Probing new physics through $B_s^* \rightarrow \mu^+ \mu^-$ decay

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(Received 24 November 2017; published 9 February 2018)

We perform a model independent analysis of new physics in $B_s^* \rightarrow \mu^+ \mu^-$ decay. We intend to identify new physics operator(s) which can provide large enhancement in the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$ above its standard model prediction. For this, we consider new physics in the form of vector, axial-vector, scalar and pseudoscalar operators. We find that scalar and pseudoscalar operators do not contribute to the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$. We perform a global fit to all relevant $b \rightarrow s \mu^+ \mu^-$ data for different new physics scenarios. For each of these scenarios, we predict $\text{Br}(B_s^* \rightarrow \mu^+ \mu^-)$. We find that a significant enhancement in $\text{Br}(B_s^* \rightarrow \mu^+ \mu^-)$ is not allowed by any of these new physics operators. In fact, for all new physics scenarios providing a good fit to the data, the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$ is suppressed as compared to the standard model (SM) value. Hence the present $b \rightarrow s \mu^+ \mu^-$ data indicates that the future measurement of $\text{Br}(B_s^* \rightarrow \mu^+ \mu^-)$ is expected to be suppressed in comparison to the standard model prediction.

DOI: [10.1103/PhysRevD.97.035007](https://doi.org/10.1103/PhysRevD.97.035007)

I. INTRODUCTION

The standard model (SM) of particle physics is in good agreement with almost all observed experimental data till date but it still has various limitations such as it cannot account for the observed matter dominance over anti-matter in our universe, the existence of dark matter and dark energy cannot be explained within the SM. Therefore, it is natural to look for physics beyond the SM. Recently, there have been several measurements in the B meson sector which do not agree with the predictions of SM. Although these measurement are not statistically significant, they can still provide signatures of physics beyond the SM. Many such measurements are in decays induced by the flavor changing neutral current quark level transition $b \rightarrow s l^+ l^-$.

The measurement of $R_K \equiv \Gamma(B^+ \rightarrow K^+ \mu^+ \mu^-)/\Gamma(B^+ \rightarrow K^+ e^+ e^-)$ [1] by the LHCb collaboration, performed in the low dilepton invariant mass-squared q^2 range ($1.0 \leq q^2 \leq 6.0 \text{ GeV}^2$), deviates from the SM prediction of $\simeq 1$ [2,3],

by 2.6σ . Recently, the measurement of $R_{K^*} \equiv \Gamma(B^0 \rightarrow K^{*0} \mu^+ \mu^-)/\Gamma(B^0 \rightarrow K^{*0} e^+ e^-)$ in the low ($0.45 \leq q^2 \leq 1.1 \text{ GeV}^2$) and central ($1.1 \leq q^2 \leq 6.0 \text{ GeV}^2$) q^2 bins [4] enforces the lepton flavor universality violation in the $b \rightarrow s l^+ l^-$ sector. R_{K^*} measurements differ from the SM prediction of $\simeq 1$ [2,3] by $2.2\text{--}2.4\sigma$ and $2.4\text{--}2.5\sigma$, in the low and central q^2 regions, respectively. This can be accounted by the presence of new physics in $b \rightarrow s \mu^+ \mu^-$ or $b \rightarrow s e^+ e^-$ sector. However, apart from the measurements of R_K and R_{K^*} , there are other measurements which show disagreement with the SM predictions. Measurement of some of the angular observables in $B \rightarrow K \mu^+ \mu^-$ [5–7] disagrees with the SM predictions [8]. In particular, P'_5 in the $4.3\text{--}8.68 \text{ GeV}^2$ -bin disagrees with the SM at the level of 4σ . This disagreement is further supported by the recent measurements by ATLAS [9] and CMS [10]. Apart from the angular observables, there is tension in the branching ratio of $B_s \rightarrow \phi \mu^+ \mu^-$ as well [11,12]. All of these discrepancies are related to the $b \rightarrow s \mu^+ \mu^-$ sector. Hence it is quite natural to account for all of these anomalies by assuming new physics in $b \rightarrow s \mu^+ \mu^-$ transition only. This is further supported by the recent global fits [13].

These anomalies are indications of new physics which one needs to explore. In [14,15], new physics in $b \rightarrow s \mu^+ \mu^-$ decays were analysed in a model independent way by making use of an effective Hamiltonian with all possible Lorentz structures. It was found that any large effects in $b \rightarrow s \mu^+ \mu^-$ sector, in particular decays like $B \rightarrow K^* \mu^+ \mu^-$ and $B_s \rightarrow \phi \mu^+ \mu^-$, can only be due to new physics vector (V)

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and axial-vector operators (A). Scalar (S) and pseudoscalar (P) operators are insignificant for these decays. This fact is corroborated by several global fits using model independent analysis. These fits suggest various new physics solutions to explain anomalies in the $b \rightarrow s\mu^+\mu^-$ decay and they are mainly in the form of V and A operators [13,16–23]. These new physics operators could affect other observables related to $b \rightarrow s\mu^+\mu^-$ transitions as well. In order to discriminate between various solutions and pin down the type of new physics responsible for all anomalies in the decays included by $b \rightarrow s\mu^+\mu^-$ transition, one should look for alternative observables. Also, it would be desirable to have an access to observables which are theoretically clean.

The purely leptonic decay of B_s^* meson is such a decay channel [24]. Its sensitivity to new physics is quite complementary to that of $B_s \rightarrow \mu^+\mu^-$ as $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$ is sensitive to different combinations of Wilson coefficients. Also, $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$ is not chirally suppressed. Further, this decay is theoretically very clean as the amplitude depends only upon decay constants which are accurately determined in the lattice QCD and the invariant mass of the process, $q^2 = m_{B_s^*}^2 = 28 \text{ GeV}^2$, is well above the charmonium states. This enables the application of an operator-product expansion for the nonlocal contributions through the quark-hadron duality. Therefore the $B_s^* \rightarrow \mu^+\mu^-$ decay rate can be accurately predicted in the standard model provided the B_s^* decay width is well known. However this width is neither measured experimentally nor accurately determined theoretically [24,25]. The B_s^* decay width is the only hindrance in the clean determination of the branching ratio. In future, this situation can improve owing to lattice QCD calculations. Using $\Gamma \sim 0.1 \text{ KeV}$, the branching ratio for this process is predicted to be $\sim 10^{-11}$ [24]. This can be within reach of next run of LHC.

The impact of $B_s^* \rightarrow \mu^+\mu^-$ on $B_s \rightarrow \mu^+\mu^-$ was studied in [26]. In [27] this decay is investigated in scalar leptoquark and family nonuniversal Z' models. It was shown that the scalar leptoquark model can provide significant enhancement in the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$ whereas in Z' model, large enhancement is not possible.

In this work we perform a model independent analysis of $B_s^* \rightarrow \mu^+\mu^-$ decay by considering new physics in the form of V , A , S and P operators. We do not consider new physics tensor operators as it is very difficult to construct a new physics model leading to tensor operators. We find that S and P operators do not contribute to the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$. We intend to identify the new physics interactions which can provide large enhancement in the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$. Also, it would be interesting to see whether $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$ can discriminate between various new physics solutions which provide a good fit to the $b \rightarrow s\mu^+\mu^-$ data. We first perform a global fit to all relevant $b \rightarrow s\mu^+\mu^-$ data and identify various new

physics solutions. For each of these solutions, we obtain predictions for branching ratio of $B_s^* \rightarrow \mu^+\mu^-$. We find that a large enhancement in $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$ is not possible due to any of these new physics scenarios.

The paper is organized as follows. In Sec. II, we discuss $B_s^* \rightarrow \mu^+\mu^-$ decay within SM and in the presence of new physics operators. In Sec. III, we discuss the methodology for the χ^2 fit. The results are presented in Sec. IV. Finally we provide conclusions in Sec. V.

II. $B_s^* \rightarrow \mu^+\mu^-$ DECAY

The B_s^* , is a vector meson, with the same quark content as the B_s meson and can be used as a complementary probe to study semileptonic B decays. The branching ratio of $B_s^* \rightarrow \mu^+\mu^-$ can be precisely measured by the end of Run III of the LHC. A detailed calculation of the SM decay rate for the $B_s^* \rightarrow \mu^+\mu^-$ process can be found in Ref. [24]. In this section we sketch the calculation, in brief, by using the effective Hamiltonian for the process $B_s^* \rightarrow \mu^+\mu^-$ in the SM and obtain the decay rate and branching ratio. We then explore new physics contributions to this process in a model-independent way by adding V , A , S and P operators to the SM effective Hamiltonian and calculate the decay rate.

A. Branching ratio of $B_s^* \rightarrow \mu^+\mu^-$ in the SM

The effective Hamiltonian for the quark level transition $b \rightarrow s\mu^+\mu^-$ within the SM is given by

$$\begin{aligned} \mathcal{H}^{\text{SM}} = & -\frac{4G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} \left[\sum_{i=1}^6 C_i(\mu) \mathcal{O}_i(\mu) \right. \\ & + C_7 \frac{e}{16\pi^2} [\bar{s}\sigma_{\mu\nu}(m_s P_L + m_b P_R)b] F^{\mu\nu} \\ & + C_9 \frac{\alpha_{em}}{4\pi} (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu \mu) \\ & \left. + C_{10} \frac{\alpha_{em}}{4\pi} (\bar{s}\gamma^\mu P_L b)(\bar{\mu}\gamma_\mu \gamma_5 \mu) \right], \end{aligned} \quad (1)$$

where G_F is the Fermi constant, V_{ij} are elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and $P_{L,R} = (1 \mp \gamma_5)/2$. The short-distance structure of the $b \rightarrow s$ transition is contained in the SM Wilson coefficients C_i 's of the respective operators $\mathcal{O}_i$'s where $O_{9,10}$ are the semileptonic operators and O_7 is the electric dipole operator. The effect of the operators $\mathcal{O}_i$, $i = 1-6, 8$ can be included in the effective Wilson coefficients by redefining $C_7(\mu) \rightarrow C_7^{\text{eff}}(\mu, q^2)$ and $C_9(\mu) \rightarrow C_9^{\text{eff}}(\mu, q^2)$.

The matrix elements of the operators $O_{7,9,10}$ can be related to the decay constant, $f_{B_s^*}$ of B_s^* meson as follows [24]

$$\begin{aligned} \langle 0 | \bar{s}\gamma^\mu b | B_s^*(p_{B_s^*}, \epsilon) \rangle &= f_{B_s^*} m_{B_s^*} \epsilon^\mu, \\ \langle 0 | \bar{s}\sigma^{\mu\nu} b | B_s^*(p_{B_s^*}, \epsilon) \rangle &= -if_{B_s^*}^T (p_{B_s^*}^\mu \epsilon^\nu - \epsilon^\mu p_{B_s^*}^\nu), \\ \langle 0 | \bar{s}\gamma^\mu \gamma_5 b | B_s^* \rangle &= 0, \end{aligned} \quad (2)$$

where ϵ^μ is the polarization vector of the B_s^* meson. In the heavy quark limit, these are related to the decay constant of B_s as, $\langle 0 | \bar{s} \gamma^\mu \gamma_5 b | B_s(p) \rangle = -i f_{B_s} p^\mu$, and hence,

$$\begin{aligned} f_{B_s^*} &= f_{B_s} \left[1 - \frac{2\alpha_s}{3\pi} \right] \\ f_{B_s^*}^T &= f_{B_s} \left[1 + \frac{2\alpha_s}{3\pi} \left(\log \left(\frac{m_b}{\mu} \right) - 1 \right) \right] \end{aligned} \quad (3)$$

We use the relations in the heavy quark limit, $f_{B_s^*}/f_{B_s} = f_{B_s^*}^T/f_{B_s} = 0.953$ as given in [24], which hold upto $O(\alpha_s)$. The SM amplitude for $B_s^* \rightarrow \mu^+ \mu^-$ is given by,

$$\begin{aligned} \mathcal{M}^{\text{SM}} &= -\frac{\alpha G_F}{2\sqrt{2}\pi} V_{ts}^* V_{tb} f_{B_s^*} m_{B_s^*} \epsilon^\mu \\ &\times \left[(C_9^{\text{eff}} + 2 \frac{m_b f_{B_s^*}^T}{m_{B_s^*} f_{B_s^*}} C_7^{\text{eff}} (\bar{\mu} \gamma_\mu \mu) + C_{10} (\bar{\mu} \gamma_\mu \gamma_5 \mu) \right] \end{aligned} \quad (4)$$

and the decay rate is calculated to be [24]

$$\begin{aligned} \Gamma(B_s^* \rightarrow \mu^+ \mu^-) &= \frac{G_F^2 \alpha^2}{96\pi^3} |V_{tb} V_{ts}^*|^2 f_{B_s^*}^2 m_{B_s^*}^2 \sqrt{m_{B_s^*}^2 - 4m_\mu^2} \\ &\times \left[\left| C_9^{\text{eff}}(m_{B_s^*}^2) + 2 \frac{m_b f_{B_s^*}^T}{m_{B_s^*} f_{B_s^*}} C_7^{\text{eff}}(m_{B_s^*}^2) \right|^2 \right. \\ &\left. + |C_{10}|^2 \right]. \end{aligned} \quad (5)$$

The decay rate shows explicit dependence on the Wilson coefficients C_7^{eff} and C_9^{eff} and operators $O_{7,9}$ unlike the decay of pseudoscalar meson B_s . To obtain the numerical result for the decay rate, we use the values of the SM Wilson Coefficients upto NNLL accuracy as given in [28]. The values of other input parameters used in the numerical analysis are as follows: $\alpha_{em} = 1/127.94$, $f_{B_s^*} = 0.2284 \pm 0.037$ GeV, $m_{B_s^*} = 5415.4 \pm 2.25$ MeV and the decay rate thus obtained is,

$$\Gamma(B_s^* \rightarrow \mu^+ \mu^-)|_{\text{SM}} = (1.14 \pm 0.04) \times 10^{-18} \text{ GeV}. \quad (6)$$

To compute the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$, we need to know the total decay width of B_s^* meson which is yet not known precisely from theoretical calculations or measurements. In order to get an estimate on the branching ratio, it is assumed that the total decay width of B_s^* , $\Gamma(B_s^{*\text{tot}})$ is comparable to the dominant decay process $B_s^* \rightarrow B_s \gamma$. From current experimental data and recent lattice QCD results, the decay width of $B_s^* \rightarrow B_s \gamma$ is found to be $\Gamma(B_s^* \rightarrow B_s \gamma) = 0.10 \pm 0.05$ KeV [24]. Using this, the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$ in the SM is calculated to be,

$$\begin{aligned} \text{BR}(B_s^* \rightarrow \mu^+ \mu^-)|_{\text{SM}} \\ = (1.14 \pm 0.57) \left(\frac{0.10 \pm 0.05 \text{ KeV}}{\Gamma_{B_s^*}^{\text{tot}}} \right) \times 10^{-11}. \end{aligned}$$

The SM branching ratio thus obtained for this process is roughly two orders of magnitude smaller than that of $B_s \rightarrow \mu^+ \mu^-$.

B. Branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$ with new physics contributions

To study new physics effects in $B_s^* \rightarrow \mu^+ \mu^-$ decay, we consider the addition of V , A , S and P operators to the SM effective Hamiltonian of $b \rightarrow s \mu^+ \mu^-$. The effective Hamiltonian in the presence of these new physics operators is given by,

$$\mathcal{H}_{\text{eff}}(b \rightarrow s \mu^+ \mu^-) = \mathcal{H}^{\text{SM}} + \mathcal{H}^{VA} + \mathcal{H}^{SP}, \quad (7)$$

where $\mathcal{H}^{VA}$ and $\mathcal{H}^{SP}$ are as

$$\begin{aligned} \mathcal{H}^{VA} &= \frac{\alpha G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} [C_9^{NP} (\bar{s} \gamma^\mu P_L b) (\bar{\mu} \gamma_\mu \mu) \\ &+ C_{10}^{NP} (\bar{s} \gamma^\mu P_L b) (\bar{\mu} \gamma_\mu \gamma_5 \mu) \\ &+ C_9'^{NP} (\bar{s} \gamma^\mu P_R b) (\bar{\mu} \gamma_\mu \mu) \\ &+ C_{10}'^{NP} (\bar{s} \gamma^\mu P_R b) (\bar{\mu} \gamma_\mu \gamma_5 \mu)] \end{aligned} \quad (8)$$

$$\begin{aligned} \mathcal{H}^{SP} &= \frac{\alpha G_F}{\sqrt{2}\pi} V_{ts}^* V_{tb} [R_S (\bar{s} P_R b) (\bar{\mu} \mu) + R_P (\bar{s} P_R b) (\bar{\mu} \gamma_5 \mu) \\ &+ R_S' (\bar{s} P_L b) (\bar{\mu} \mu) + R_P' (\bar{s} P_L b) (\bar{\mu} \gamma_5 \mu)] \end{aligned} \quad (9)$$

where C_9^{NP} , C_{10}^{NP} , $C_9'^{NP}$, $C_{10}'^{NP}$, R_S , R_P , R_S' , R_P' are new physics couplings.

We first compute the decay rate by considering new physics in the form of S and P operators. From the structure of these operators, it can be seen that the matrix elements which appear in the calculation of the amplitude are $\langle 0 | \bar{s} b | B_s^* \rangle$ and $\langle 0 | \bar{s} \gamma^5 b | B_s^* \rangle$. Using the first and third relations defined in Eq. (2), one can show that,

$$\langle 0 | \bar{s} b | B_s^* \rangle = 0, \quad (10)$$

$$\langle 0 | \bar{s} \gamma^5 b | B_s^* \rangle = 0. \quad (11)$$

Hence the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$ is not affected by new physics in the form of S and P operators.

We now examine the contribution from V and A operators. Note that the matrix elements accompanying C_9^{NP} , and C_{10}^{NP} in the Hamiltonian for V and A contributions have the same Lorentz structure as the SM one for C_9 , while the matrix elements accompanying $C_{10}'^{NP}$, and C_{10}^{NP} are the same as the SM ones for C_{10} . The only difference being that unlike SM, new physics has right-handed chiral

operator as well. Using the relationship between the matrix elements and decay constants defined in Eq. (2), the decay rate including NP VA contribution is obtained to be,

$$\Gamma(B_s^* \rightarrow \mu^+ \mu^-) = \frac{G_F^2 \alpha^2}{96\pi^3} |V_{tb} V_{ts}^*|^2 f_{B_s^*}^2 m_{B_s^*}^2 \sqrt{m_{B_s^*}^2 - 4m_\mu^2} \left[\left| C_9^{\text{eff}}(m_{B_s^*}^2) + 2 \frac{m_b f_{B_s^*}^T}{m_{B_s^*} f_{B_s^*}} C_7^{\text{eff}}(m_{B_s^*}^2) + C_9^{NP} + C_9'^{NP} \right|^2 + |C_{10} + C_{10}^{NP} + C_{10}'^{NP}|^2 \right]. \quad (12)$$

III. METHODOLOGY

As new physics in the form of S and P operators do not contribute to the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$, we consider new physics only in the form of V and A operators. We consider various possible combinations of these new physics operators and obtain constraints on their coefficients by doing a global fit to all CP conserving observables in the $b \rightarrow s \mu^+ \mu^-$ sector. Most of these observables probe the kinematical distribution in $B \rightarrow K^* \mu^+ \mu^-$ and $B_s^0 \rightarrow \phi \mu^+ \mu^-$. The observables used in the fit are:

- (1) The branching ratio of $B_s \rightarrow \mu^+ \mu^-$ which is $(2.9 \pm 0.7) \times 10^{-9}$ [29,30].
- (2) The measurements of R_K [1] and R_{K^*} [4].
- (3) The differential branching ratio of $B^0 \rightarrow K^0 \mu^+ \mu^-$ [31].
- (4) The differential branching ratio of $B^+ \rightarrow K^+ \mu^+ \mu^-$ [31,32].

- (5) The experimental measurements for the differential branching ratio of $B \rightarrow X_s \mu^+ \mu^-$ [33].
- (6) The nine measured observables in different q^2 bins in the decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ [6].
- (7) The differential branching ratio of $B^+ \rightarrow K^{*+} \mu^+ \mu^-$ [34].
- (8) The measurements of the angular observables and the differential branching ratio of $B_s^0 \rightarrow \phi \mu^+ \mu^-$ [12,32].

A χ^2 fit is done by using CERN minimization code MINUIT [35,36]. The χ^2 function is constructed as

$$\chi^2(C_i) = (\mathcal{O}_{th}(C_i) - \mathcal{O}_{exp})^T \mathcal{C}^{-1} (\mathcal{O}_{th}(C_i) - \mathcal{O}_{exp}). \quad (13)$$

The χ^2 function is minimized to get the best fit points and the theoretical predictions, $\mathcal{O}_{th}(C_i)$ are calculated using FLAVIO [37]. $\mathcal{O}_{exp}$ are the experimental measurements of the observables used in the fit. We obtained the total covariance matrix $\mathcal{C}$ by adding the individual theoretical and experimental covariance matrices.

We consider all possible combinations of new physics operators and obtain $\Delta\chi^2$ between the new physics best-fit points and SM best fit point. The fit results are presented Table I. We consider new physics only in the Wilson coefficients defined in Table I and all other Wilson coefficients are considered as SM like. We want to see if any new physics scenario can provide large enhancement in the branching ratio of $B_s^* \rightarrow \mu^+ \mu^-$ above its SM value.

TABLE I. Calculation of the branching ratios of $B_s^* \rightarrow \mu^+ \mu^-$ for various new physics scenarios. Here $\Delta\chi^2 = \chi_{SM}^2 - \chi_{bf}^2$ and χ_{bf}^2 is the χ^2 at the best fit points. We provide 1σ range of the new physics couplings for the one parameter fits and the central values for multiple parameter fits.

Scenario	New physics couplings	$\Delta\chi^2$	Branching Ratio
$C_i = 0$ (SM)	-	0	$(1.14 \pm 0.57) \times 10^{-11}$
C_9^{NP}	-1.24 ± 0.18	43.27	$(0.86 \pm 0.43) \times 10^{-11}$
C_{10}^{NP}	0.91 ± 0.19	29.47	$(0.91 \pm 0.46) \times 10^{-11}$
C_9'	0.13 ± 0.16	0.66	$(1.18 \pm 0.59) \times 10^{-11}$
C_{10}'	-0.11 ± 0.13	0.68	$(1.17 \pm 0.59) \times 10^{-11}$
$C_9^{NP} = C_{10}^{NP}$	0.01 ± 0.18	0.001	$(1.14 \pm 0.58) \times 10^{-11}$
$C_9^{NP} = -C_{10}^{NP}$	-0.65 ± 0.11	43.04	$(0.81 \pm 0.41) \times 10^{-11}$
$C_9' = C_{10}'$	-0.04 ± 0.17	0.06	$(1.15 \pm 0.58) \times 10^{-11}$
$C_9' = -C_{10}'$	0.07 ± 0.08	0.81	$(1.18 \pm 0.59) \times 10^{-11}$
$[C_9^{NP}, C_{10}^{NP}]$	$[-1.10, 0.33]$	47.33	$(0.80 \pm 0.40) \times 10^{-11}$
$[C_9', C_{10}']$	$[0.08, -0.07]$	0.81	$(1.19 \pm 0.59) \times 10^{-11}$
$[C_9^{NP} = C_{10}^{NP}, C_9' = C_{10}']$	$[-0.02, -0.02]$	0.07	$(1.15 \pm 0.57) \times 10^{-11}$
$[C_9^{NP} = -C_{10}^{NP}, C_9' = -C_{10}']$	$[-0.67, 0.16]$	46.27	$(0.88 \pm 0.44) \times 10^{-11}$
$[C_9^{NP}, C_{10}^{NP}, C_9', C_{10}']$	$[-1.31, 0.26, 0.34, -0.25]$	56.04	$(0.91 \pm 0.46) \times 10^{-11}$

IV. RESULTS AND DISCUSSIONS

The fit results for various new physics scenarios, along with the corresponding predictions for the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$, are presented in Table I.

Global fits suggest that a large negative C_9^{NP} contribution can provide a good fit to the data, i.e., having a large $\Delta\chi^2$. A large negative value of C_9^{NP} on the one hand allows large deviations in P'_5 with respect to the SM and on the other hand drives $R_{K^{(*)}}$ to a value lower than their SM predictions of ~ 1 , in agreement with the experimental measurements. Another good fit scenario is $C_9^{NP} = -C_{10}^{NP}$. This corresponds to an operator with only left-handed leptons and is predicted by various new physics models. A positive value of C_{10}^{NP} can also improve the fit however the improvement is moderate. The effect of individual chirality flipped operators are almost insignificant i.e., they hardly improve the fit.

From Table I, it can be seen that the new physics scenarios which provide a good fit to the data, suppress the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$ as compared to its SM value. In order to understand this, let us first consider a good-fit scenario $C_9^{NP} < 0$. From Eq. (12), it can be seen that the branching ratio, in the presence of the new physics operator O_9^{NP} , depends upon $|C_9^{\text{eff}} + C_9^{NP}|^2$. Now as $C_9^{\text{eff}} \sim 4.2$ in the SM, a large negative value of C_9^{NP} will decrease the effective Wilson coefficient $|C_9^{\text{eff}} + C_9^{NP}|^2$ and hence will result in the suppression of the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$. Another scenario which provides a good fit to the data is $C_9^{NP} = -C_{10}^{NP}$. In this scenario the effective Wilson coefficient $|C_9^{\text{eff}} + C_9^{NP}|^2$ becomes less than the SM value thereby lowering the branching ratio. In addition to this, a positive value of C_{10}^{NP} , in this scenario, reduces the value of the effective Wilson coefficient $|C_{10} + C_{10}^{NP}|^2$, as in the SM the value of C_{10} is negative. Therefore in this scenario, the effect of both C_9^{NP} and C_{10}^{NP} is to suppress the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$ in comparison to the SM.

Other scenarios which provide a good fit to the data, similarly have $C_9^{NP} < 0$ and $C_{10}^{NP} > 0$. These scenarios, in addition have small positive and negative values of C'_9 and C'_{10} respectively. This in principle could lead to some enhancement in the branching ratio. However the allowed values of C'_9 and C'_{10} are very small as compared to the

values of C_9^{NP} and C_{10}^{NP} , so the effect of the latter dominates leading to suppression in the branching ratio.

The remaining scenarios have $\Delta\chi^2$ small and hence they do not provide a good fit to the data. These scenarios cannot induce significant deviation in the branching ratio from the SM value. This is because the new physics Wilson coefficients for these scenarios are very small as compared to the SM and hence they cannot lead to a significant enhancement or suppression of the branching ratio.

Thus none of the new physics scenarios can provide large enhancement in the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$ above its SM value. In scenarios where a good fit to the data is obtained, $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$ is seen to be suppressed as compared to the SM value. Hence, most likely, the future measurements are expected to observe $B_s^* \rightarrow \mu^+\mu^-$ decay with a branching ratio less than its SM prediction.

V. CONCLUSIONS

The new physics sensitivity of $B_s^* \rightarrow \mu^+\mu^-$ decay is quite complementary to that of $B_s \rightarrow \mu^+\mu^-$ decay as it is sensitive to different combinations of Wilson coefficients. More importantly, this decay is theoretically very clean. The decay rate can be accurately predicted in the standard model provided the B_s^* decay width is well known. In this work we perform a model independent analysis of new physics in $B_s^* \rightarrow \mu^+\mu^-$ decay with an intend to identify the Lorentz structure of new physics which can provide large enhancement in the branching ratio of $B_s^* \rightarrow \mu^+\mu^-$ above its SM value. For this, we consider new physics in the form of V , A , S and P operators. We show that the S and P operators do not contribute to $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$. We then perform a global fit to all relevant $b \rightarrow s\mu^+\mu^-$ data for different combinations of new physics V and A operators. For each of these scenarios, we predict $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$. We find that none of these scenarios can significantly enhance $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$. All new physics operators which provide a good fit to the present $b \rightarrow s\mu^+\mu^-$ data indicate suppression in $\text{Br}(B_s^* \rightarrow \mu^+\mu^-)$ in comparison to its SM prediction.

ACKNOWLEDGMENTS

We thank Ashutosh Kumar Alok for useful discussions.

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